Kaon and Φ production vs Participants in Nuclear Collisions

H Białkowska† and W Retyk‡

† Institute for Nuclear Studies, Warsaw, Poland
‡ Institute of Experimental Physics, Warsaw University, Warsaw, Poland

Abstract. Data on kaon and Φ production in nuclear collisions as a function of centrality are analysed both at AGS and SPS energy range. We compare the results of several experiments, looking for common trend in 'participant scaling' of production yields. We find a smooth description of scaled kaon and Φ yields as a function of participant density. We also show a participant density dependence of kaons and Φ produced in the forward hemisphere for proton-nucleus collisions.

There exists a large amount of data, both at AGS and SPS, where charged kaon production in nuclear collisions is studied. Kaons represent between 70 and 80 % of all strangeness produced, and thus carry important information on global strangeness.

The main physics question we want to address is strangeness evolution with centrality.

The idea of centrality is a geometrical one, and it refers to an impact parameter b of the colliding nuclei. In real life, impact parameter is not accessible to measurement. One has to measure some quantity x related to b, use some model to translate x into b, and only then one can calculate the number of participants in a collision, N_w.

Variable x can be the transverse energy E_T (as used by NA50), charged particle multiplicity N_{ch} (used by WA97) and forward, or zero degree energy, E_{veto}, used by AGS experiments and NA49.

When studying global strangeness characteristics, it is important to look at 4π multiplicity, and it often involves some extrapolation. In the following we will show kaon data from AGS [1], NA49 [2] and WA97 [3], [4]. AGS data and NA49 data are measured and extrapolated by the respective authors in the full phase space. The WA97 data are p_T integrated but measured/extrapolated to only one unit of rapidity, centered at midrapidity. In order to compare with NA49, we will extrapolate these data to 4π, assuming same scaling factor from midrapidity to 4π as in NA49.

Fig. 1 [1] shows the charged kaon per participant yields vs participant number in Au - Au, Si - Al and Si - Au collisions at AGS energies. The number of participants is determined directly from the total spectator energy, measured by the forward calorimeter.

Fig. 2 [2] shows the average of charged kaons per participant vs participant number from Pb - Pb collisions at 158 GeV/c. Here the number of participants was determined directly as a (measured) total number of net baryons, that is baryons minus antibaryons.

Both plots show the same tendency. The yield of charged kaons per participant increases significantly with centrality, as measured by the participant number. Both at AGS and SPS the number of participants does not represent a good scaling variable.
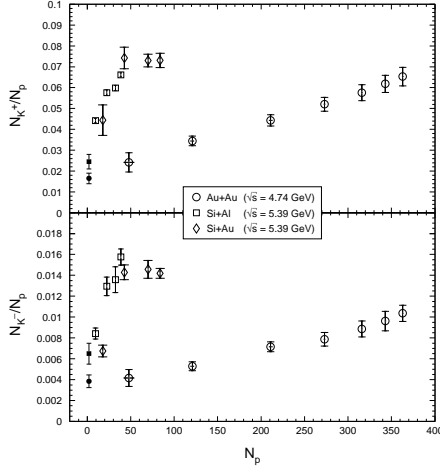
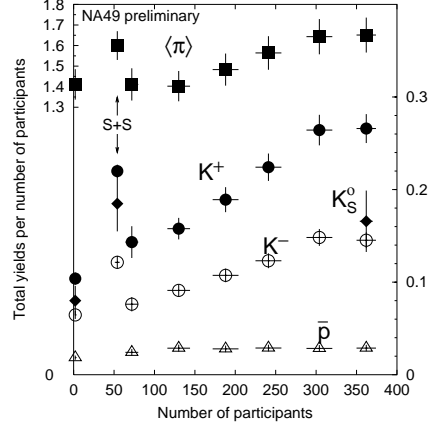**Figure 1.** Charged kaon per participant yields vs number of participants at AGS energies [1].

Figure 2. Average of charged kaons, pions and anti-protons per participant vs number of participants at SPS energies (NA49) [2]. Points other than marked 'S+S' come from Pb+Pb reaction.

Apparently the same number of participants does not represent the same geometry for different nuclei; clearly, dilute surfaces of big nuclei make a difference.

H.Satz and M.Nardi [5] have suggested to use the average density of participants in nuclear collisions as a centrality parameter. The following formulae give total number of participants and average density of participant nucleons at impact parameter b for nucleus A - nucleus B collision.

$$\rho_w^{AB}(\vec{b}, \vec{s}) = A T_A(\vec{s}) \Big\{ 1 - \Big[1 - \sigma_0 \, T_B(\vec{b} - \vec{s}) \Big]^B \Big\}$$
$$+ B \, T_B(\vec{b} - \vec{s}) \Big\{ 1 - [1 - \sigma_0 \, T_A(\vec{s})]^A \Big\}$$
$$\langle \rho_w^{AB}(b) \rangle = \int \mathrm{d}^2 s [\rho_w^{AB}(\vec{b}, \vec{s})]^2 / \int \mathrm{d}^2 s \; \rho_w^{AB}(\vec{b}, \vec{s}) \; .$$

In Fig. 3 we show the average yield of charged kaons per participant vs participant density for all data sets discussed. Here we have taken the same definition of participants for all experiments, and have calculated the average participant density on the basis of percentage of $\sigma_{inelastic}$ and hence b, taking Glauber formulae with Saxon - Woods density. Notice that it changes slightly the number of participant used in all quoted experiments, but assures equal treatment of all data sets.

Two observations are in order. First, the average participant density seems to take out large part of difference between collisions of different nuclei. Second, there still seems to be an increase of kaon/participant with participant density at SPS, although most central WA97 point is different from NA49.

These observations have encouraged us to look at the Φ meson production as a function of centrality. Φ is much less copiously produced, but it carries a potentially very important information on the production of $s\bar{s}$ state
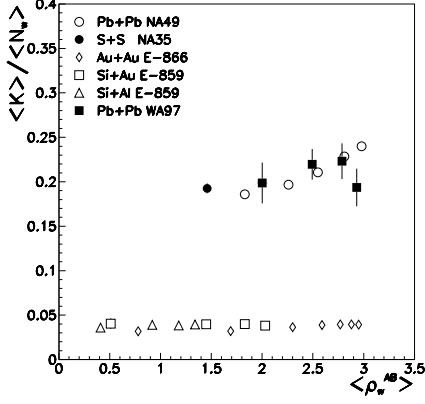
Figure 3. The average yield of charged kaons per participant vs participant density from different experiments (extrapolated to 4π).
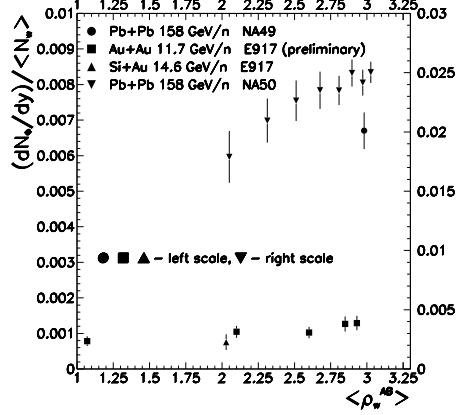

Figure 4. dN/dy of Φ mesons per participant vs participant density from different experiments. Data sets has different scales.

At AGS the E917 experiment measures Φ at 11.7GeV/c/N. On This Conference the authors have shown new (although still preliminary) data, which they kindly have allowed us to use [6]. These data come from limited rapidity range, $1.2 < y < 1.6$.

The NA50 experiment [7] has shown the Φ production dependence on the number of participants in Pb - Pb collisions at 158 GeV/c. This experiment measures the $\mu^+\mu^-$ decay channel, and covers midrapidity range and large m_T, bigger than 1.5 GeV/c. Finally, NA49 has measured Φ production in the K^+K^- decay channel, with large rapidity and transverse momentum coverage, in central Pb - Pb (5% of σ_{inel}), [8].

We have recalculated the Φ yields, integrating the transverse spectra and selecting (approximately) the same scaled rapidity range. The average participant density and number of participants were also calculated starting from b and N_w range. Fig. 4 shows the compilation of all available AGS and SPS data.

An increase of Φ per participant yields with the average participant density is seen at AGS energy, and a significant increase is observed from SPS data. For the highest centrality Pb - Pb data, there is a discrepancy in the absolute Φ yield - NA50 results exceed NA49 yield by factors of between 3 and 4.

We would like to extend this study into proton-nucleus collisions. For these reactions, measurement of slow ('grey' in old emulsion terminology) protons serves as a centrality trigger. The measured number of slow protons can be translated into the number of collisions ν, assuming independence of successive collisions. The full number of participants is then $1 + \nu$. Using the same definition as for nucleus-nucleus collisions, participants density becames in the case of proton-nucleus reaction the above defined number of participants.

For the proton - nucleus collisions, there is an important difference between center of mass hemispheres. In the backward hemisphere effects of target fragmentation, energy loss and cascading contribute to the overall multiplicity. In the forward hemisphere we deal with fragmentation of projectile proton that has hit several

nucleons. At midrapidity we have contributions from both mechanisms, or a 'spill - over'.

AGS experiment E910 ([9], [10]) has measured Λ and K^0 production for centrality selected p - Au collisions at 17.5 GeV/c. They observe a significant rise of strange particle multiplicity with the number of collisions, ν, saturating for higher ν.

SPS experiment NA49 has measured charged kaon production in centrality selected p - Pb collisions at 158 GeV/c [11] and [8]. Here the rapidity coverage extends over forward hemisphere only. Thus we deal both with the projectile fragmentation and a spill - over from the target hemisphere. Fig. 5a shows the average charged kaon multiplicity as a function of the number of participants N_w. In order to account for the influence of the target fragmentation, we propose to normalize the kaon yield not by N_w but by the $N_w/2 + 1$, as shown in Fig. 5b. We observe a definite kaon enhancement.
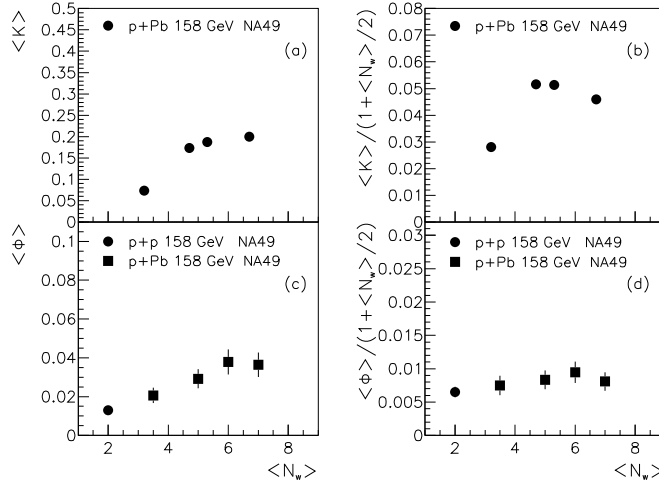

Figure 5. The average multiplicity of charged kaons (a,b) and Φ mesons (c,d) in the forward hemisphere as a function of the number of participants. In the right panels multiplicity is normalized in order to account for the influence of the target fragmentation as a function of the number of participants.

Experiment NA49 has also measured Φ (in the K^+K^- decay channel) production in centrality selected p - Pb collisions [8]. Fig. 5c shows the average yield of Φ (in the forward hemisphere) as a function of the number of participants, and Fig. 5d - Φ yield normalized by $(N_w/2+1)$. A slow increase from pp point, measured in the same experiment, with N_w is seen.

As a last observation we would like to show a completely new approach to Φ enhancement. Fig. 6 shows the average Φ yield normalized to the average pion yield in proton - proton collisions at 158 GeV/c, studied as a function of charged particle multiplicity [8]. For these data there is no asymmetry of the CM system, and measurement in the forward hemisphere allows for conclusions for the full phase

space. While it is hard to define 'centrality' for proton - proton collisions, we find it interesting to observe 'strangeness enhancement' as a function of - presumably - 'violence' of the pp collision.
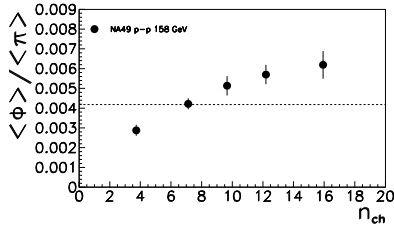

Figure 6. The average Φ yield normalized to the average pion yield in proton - proton collisions at 158 GeV/c as a function of charged particle multiplicity. The horizontal dashed line indicates the cross-section weighted average.

To sum up, we make the following observations:

- Participant density allows for smooth comparison of various nuclear collisions
- At AGS average kaon yield per participant stays approximately constant as a function of participant density
- At SPS there is a hint for an increase of kaon/participant as a function of participant density
- The Φ yield per participant definitely increases with participant density both at AGS and SPS
- Both kaon and Φ yields increase with participant density in p - nucleus collisions
- Φ production in proton - proton collisions normalized to the average pion yield increases with charged particle multiplicity

The above observations have to be taken into account when attempting to describe and interpret strangeness enhancement in nuclear collisions.

Acknowledgments

[1] L.Ahle et al., Phys.Rev. C60 (1999) 044904
[2] J.Bächler et al., Nucl.Phys. A661 (1999) 45c
[3] E.Andersen et al., CERN-EP/99-29; F.Antinori et al., Nucl.Phys. A661 (1999) 130c
[4] N.Carrer, these proceedings
[5] M.Nardi, CERN Heavy Ion Physics School CHIPS'99, June 1999; H.Satz, M.Nardi private comm.
[6] B.Back, these proceedings
[7] M.C.Abreu et al. Nucl.Phys. A661 (1999) 534c and C.Quintans, these proceedings
[8] S.V.Afanasiev et al., Production of Φ Mesons in p + p, p + Pb and Pb + Pb Collisions at $E_{beam} = 158 GeV/u$, June 2000, submitted to Phys.Lett.
[9] I.Chemakin et al., nucl-ex/0003010v2
[10] R. Soltz, these proceedings
[11] C.Höhne for the NA49 collaboration, Nucl.Phys A661 (1999) 485c